

On The Spectra of Boron

A DISSERTATION

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BY

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ON THE SPECTRA OF BORON

BY F. R. SMITH

Inspection of the previously published data on boron reveals less than a dozen spectral lines attributed to this element in the region of longer wave length than 1850 Angstrom units.^{1,2} A consideration of the series spectra of the various stages of ionization of boron however shows that a considerably larger number of lines is to be expected in this region. The present work was undertaken to see whether with the vacuum spark as a source and spectrographs of medium dispersion some of these lines could be found.

I. APPARATUS AND PROCEDURE

The apparatus for the production of the vacuum spark has been described by Sawyer and Paton.³ In the present work, however, the

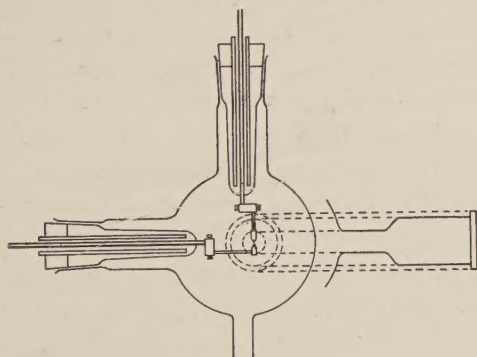


FIG. 1. *Diagram of spark-box.*

metal spark-box there used was replaced by a glass one of new design which was found to be much more convenient. (Fig. 1.) Arms about four inches long and one and one-half inches in diameter were attached,

¹ H. Kayser, *Handbuch der Spectroscopie*, 5, 6, 7.

² A. Fowler, *Report on Series in Line Spectra*, p. 155.

³ *Astrophysical Journal*, 57, p. 279; 1923.

one to the bottom and one to the side of a two-liter Pyrex glass flask. These arms were fitted with hollow ground-glass stoppers which projected nearly to the center of the box. A hundred mil tungsten lead wire was sealed in each of the stoppers. Glass tubes placed around the leads inside the stoppers gave greater dielectric strength. A wire of sufficient length to reach to the center of the box was attached to each lead. About one inch of the extremity of the wire was bent at right angles and a spring clamp for holding the material to be sparked was mounted on the end of the wire. The arms formed by bending the wire allowed the sample to be moved through the arc of a circle when the stopper was rotated. Since the two arms carrying the electrodes were at right angles to each other considerable adjustment of the spark-gap could be made by rotating the stoppers without opening the spark-box. A tube about seven inches long and two and one-half inches in diameter projected from the bulb at right angles to each of the arms carrying an electrode. The end of this tube was ground flat and a quartz window was sealed to it through which the spark was observed. The long tube prevented sputtering of the window. The neck of the flask formed the outlet leading to the evacuating system which consisted of a Kurth type mercury vapor pump supported by a Cenco Hyvac fore-pump. A trap immersed in liquid air was placed between the spark-box and the pump to condense any water or mercury vapor present.

A small quantity of boron was available in the form of small rods which had been prepared by Weintraub. The resistivity of boron at ordinary temperatures is very high, Weintraub⁴ giving its conductivity at 0°C as $0.5-0.6 \times 10^{-6}$ reciprocal ohms per cm as compared to 1.8 for silicon and 0.7×10^6 for copper. This made it difficult to start a spark between boron electrodes. The spark-gap had to be made very small, less than one mm, and the discharge obtained was not as heavy as that produced by the same electrical circuit with metallic electrodes, or even with silicon. A much heavier spark was obtained when a piece of shell charcoal was used for one electrode. The resistance of boron decreases very rapidly as the temperature rises. For example Weintraub, loc. cit., gives the resistance of a certain sample of boron as 775000 ohms at 27°C but less than a hundred-thousandth of this value at about 500°C. On account of this large negative temperature coefficient of resistance the current would increase rapidly when the

⁴ Journal Ind. and Eng. Chem., 5, p. 106; 1913, Trans. Am. Electrochem. Soc., 16, p. 165; 1909.

spark was once started and if the spark continued for any appreciable length of time the boron would become heated to incandescence and the electrodes would disintegrate. Also the heating would cause so much expansion that the small gap would become closed, the electrodes would fuse together and would crumble when separated. As the supply of boron was very limited it was necessary to watch the sparking constantly to prevent these occurrences. A hand-operated switch in the primary circuit of the transformer was located near the spark-box to control the interval between the sparks and their duration. This switch could be closed only a fraction of a second, perhaps one-half, while enough time, one or two seconds, had to be allowed to elapse between successive sparks so the electrodes could cool below the temperature of incandescence. Even with the greatest care the electrodes would usually crumble and have to be replaced two or three times during an exposure.

II. DATA

Spectrograms were taken in the region $\lambda 2300$ – $\lambda 4200$ with a Hilger E2 quartz spectrograph using Cramer contrast plates oiled with Nujol and in the region $\lambda 3800$ – $\lambda 5800$ with a two prism glass spectrograph built in the Physics department shops at the University of Michigan. The iron arc spectrum was used as a standard. The plates were measured on a Gaertner comparator and reduced by the Hartmann formula.

The data were checked for gaseous impurities against the vacuum spark data obtained in the laboratory on other elements and against the published lists of spectra of suspected elements. The chief impurities were iron from the clamps, calcium and hydrogen.

The spectral lines listed in Table 1 are thought to be all due to boron. All were measured on several plates and the wave lengths are considered to be accurate to one-tenth of an Angstrom unit or better, except possibly in the longest wave lengths.

TABLE 1. *Lines in the vacuum spark spectrum of boron.*

Intensity	Wave-lengths (In air)	Wave-numbers (In vacuum)	Classification
1	4940.87	20233.7	B II 3^3D-4^3P
1	4937.70	20246.7	
1	4901.85	20394.8	
0	4849.6	20614.3	B II 3^1D-4^1F

TABLE 1. *Continued.*

Intensity	Wave-lengths (In air)	Wave-numbers (In vacuum)	Classification
0	4829.0	20702.7	B II 3^1D-4^1P
0	4761.4	20996.5	B II $4^1F-8^1D ?$
2	4677.9	21371.2	B III 4^2D-5^2P
5	4497.71*	22227.3	B III $4^2F-5^2G^*$
0	4493.1	22249.9	
2	4472.70*	22351.6	B II $3^3P_2-4^3S^*$
2	4471.97*	22355.3	B II $3^3P_{0,1}-4^3S^*$
1	4402.95	22705.7	
0	4394.25	22760.5	
2	4382.95	22809.3	
1	4375.60	22847.6	
1	4371.69	22868.1	
3	4355.68	22952.1	
1	4353.17	22965.3	
2	4344.77	23009.7	
2	4311.9	23185.2	B III 4^2P-5^2D
0	4290.90	23298.6	B II 3^1P-4^1P
0	4272.86	23397.0	
1	4231.07	23628.0 ?	
1	4226.15	23655.5	
0	4214.17	23722.8	B II 3^1P-4^1D
0	4201.86	23792.3	
1	4194.82	23832.2	
0	4192.72	23844.2	
2	4164.43	24006.2	
1	4150.71	24085.5	
10	4121.68*	24254.8	B II $3^3D-4^3F^*$
0	4090.79	24438.3	
1	4082.62	24487.2	
1	4050.13	24683.6	
2	4039.57	24748.1	
0	4027.82	24820.4	
1	4026.47	24828.7	
4	3871.39	25828.2	
0	3754.86	26624.6	
0	3493.85	28613.5	
25	3451.22*	28966.0	B II $2^1S-2^3P_1^*$
5	3360.09	29752.6	
3	3323.34	30081.6	B II 3^1P-5^1S
3	3302.51	30271.3	
1	3282.01	30460.4	
3	3260.74	30659.1	B II 3^1D-5^1F
1	3191.84	31320.9	
0	3178.24	31454.9	

* Previously classified.

TABLE 1. *Continued.*

Intensity	Wave-lengths (In air)	Wave-numbers (In vacuum)	Classification
1	3158.54	31651.1	
1	3136.85	31870.0	B II $3^3P_2-4^3D$
1	3135.64	31872.1	B II $3^3P_{0,1}-4^3D$
1	3112.50	32119.2	
2	3102.09	32227.0	B II 3^3D-5^3P
1	3086.06	32394.4	
1	3013.28	33176.9	
1	2981.53 ?	33530.0	B II $3^1P-5^1D ?$
1	2918.15*	34258.3	B II $3^3D-5^3F^*$
1	2889.72	34595.3	
1	2888.32	34612.0	
1	2886.80	34630.2	
1	2809.72	35580.2	
5	2785.14	35894.3	
8	2779.26	35970.2	
1	2749.89	36354.4	
1	2731.94	36593.2	
0	2698.35	37048.7	
0	2697.72	37057.4	
1	2696.84	37069.4	
2	2695.18	37092.3	
0	2694.23	37105.3	
0	2671.94	37414.9	
1	2652.81	37684.7	B II $3^3P_2-5^3S$
1	2652.58	37687.9	B II $3^3P_{0,1}-5^3S$
1	2610.26	38298.9	
1	2566.40	38953.4	B II 3^1P-6^1D
3	2566.26	38955.5	B II 3^1S-4^1P
2	2557.52	39088.6	
2	2515.06	39748.5	B II 3^3D-6^3F
2	2514.96	39750.1	
6	2514.39	39759.1	Near $\lambda 2514.33$, Si I, but strong neighbor- ing Si lines absent.
1	2508.45	39853.2	
12	2497.72*	40024.4	B I $2^2P_2-3^2S^*$
10	2496.80*	40039.2	B I $2^2P_1-3^2S^*$
2	2446.10	40869.0	
2	2445.11	40885.6	
1	2436.95	41022.4	
4	2434.95	41056.13	
5	2432.29	41101.0	B II 3^3S-4^3P
1	2430.82	41125.9	
1	2415.06	41394.3	

* Previously classified.

TABLE 1. *Continued.*

Intensity	Wave-lengths (In air)	Wave-numbers (In vacuum)	Classification
1	2400.03	41654.5	B II 3^3P-5^3D
3	2395.07	41739.7	
4	2369.96	42182.0	
3	2363.88	42290.5	
1	2363.51	42297.1	
2	2357.03	42413.3	
2	2355.25	42445.4	B III $3^2P_2-4^2S$ B III $3^2P_1-4^2S$
	2267.0*	44097	
	2266.4*	44109	

* Given by Eder and Valenta, beyond the range of this work.

III. CLASSIFICATION OF LINES

BORON I

Rydberg⁵ supposed the pair $\lambda\lambda 2497.72, 2496.80$ to be the first doublet of the sharp and principal series of B I. This view was confirmed by Popow's⁶ observations of the Zeeman effect. The pair at $\lambda\lambda 2089.80, 2088.90$ given by Eder and Valenta⁷ and a pair found by Millikan and Bowen⁸ at $\lambda\lambda 1826.41, 1825.87$ have the same frequency difference as the doublet at $\lambda 2498$ so probably belong to either the sharp or diffuse series of B I. Nothing has been found in the course of the present work to extend the knowledge of this spectrum.

BORON II

Millikan and Bowen⁹ have classified several lines as arising from deep lying terms in the spectrum of B II. Their values are summarized in Table 2, page 293.

In the investigation herein reported two other pairs, $\lambda 2652.81$ ($\nu = 37684.7$), $\lambda 2652.58$ ($\nu = 37687.9$) and $\lambda 3136.85$ ($\nu = 31870.0$), $\lambda 3136.64$ ($\nu = 31872.1$), were found with the same frequency separation as the $3^3P_2P_{0,1}$ terms. The latter pair lies near the value of the 3^3P-4^3D lines as determined from Millikan and Bowen's terms, viz., $59006.5 - 28640.4 = 30366.1$ and $59010.0 - 28640.4 = 30369.6$. But since Milli-

⁵ Fowler, loc. cit., p. 155.

⁶ S. Popow, Archives des sciences phys. et. nat., 36, p. 11; 1913.

⁷ J. M. Eder and E. Valenta, Denkschr. Wien. Akad., 60, p. 307; 1893; Beitrage zur Photochemie und Spectralanalyse, p. 82; 1904.

⁸ R. A. Millikan and I. S. Bowen, Proc. Nat. Acad. Sci., 10, p. 199; 1924; Phys. Rev., 24, p. 209, 1924.

⁹ I. S. Bowen and R. A. Millikan, Phys. Rev., 26, p. 310; 1925.

kan and Bowen based these term values upon two independent estimates the differences are only approximations to the frequencies of the 3^3P-4^3D lines so the pair at $\lambda 3137$ is used with Millikan and Bowen's

TABLE 2. *B II lines and terms by Millikan and Bowen.*

Int.	Wave-lengths (I. A., vac.)	Wave-numbers	Classification
1	4474.08	22351.0	$3^3P_2-4^3S$
1	4473.37	22354.5	$3^3P_{0,1}-4^3S$
6	4122.99	24254.2	3^3D-4^3F
2	2918.98	34258.5	3^3D-5^3F
3	1082.10	92412.8	$2^3P_2-3^3S$
3	1081.88	92432.1	$2^3P_{0,1}-3^3S$
3	882.69	113289.9	$2^3P_2-3^3D$
3	882.55	113308.2	$2^3P_{0,1}-3^3D$
0	731.46	136712.9	2^3P-4^3D
10	3452.33	28965.9	$2^1S-2^3P_1$
5	1842.83	54264.3	2^1P-3^1S
3	1378.95	72519.1	2^1P-3^1D
6	1362.46	73396.5	2^1S-2^1P

Term Values		Effective Quantum Number*
3^3S	72930.8	2.4513
4^3S	36655.5	3.4596
2^3P_2	165343.9	1.6289
$2^3P_{0,1}$	165362.7	
3^3P_2	59006.5	2.7268
$3^3P_{0,1}$	59010.0	
3^3D	52054.2	2.9031
4^3D	28640.4	3.9139
4^3F	27800.0	3.9726
5^3F	17795.7	4.9650
2^1S	194325.9	1.5026
3^1S	66665.1	2.5654
2^1P	120929.4	1.9047
3^1D	48410.3	3.0104

* The effective quantum numbers throughout this article are calculated with $N = \text{NH}$.

value of 4^3D to fix accurately the 3^3P levels and consequently the 4^3S levels as follows:

4^3D	28640.4	4^3D	28640.4
$3^3P_2-4^3D$	31870.0	$3^3P_{0,1}-4^3D$	31872.1
3^3P_2	60510.4	$3^3P_{0,1}$	60512.5
3^3P_2	60510.4	$3^3P_{0,1}$	60512.5
$3^3P_2-4^3S$	22351.6	$3^3P_{0,1}-4^3S$	22355.3
4^3S	38158.0	4^3S	38157.2

This gives an effective quantum number of 2.6927 for 3^3P_2 which is consistent with the number 1.6289 from Millikan and Bowen's value of 2^3P_2 . In the case of the 4^3S term the effective quantum number comes out 3.3989 as compared with 2.4513 for their 3^3S term. This is unusual as the effective quantum numbers of the S series increase instead of decrease with the higher terms in the case of the Mg I, Al II and Si III atoms. Since these and B II are atoms of similar electronic configuration they might be expected to exhibit the same behavior in their series and no explanation of the difference is offered. The classification seems to be justified by the fact that this is the only pair found in this region. Further, if the other pair found to have the same frequency difference, $\lambda\lambda 2652.81, 2652.58$, is classified as 3^3P-5^3S it gives

	3^3P_2	60510.4		$3^3P_{0,1}$	60512.5
	$3^3P_2-5^3S$	37684.7		$3^3P_{0,1}-5^3S$	37687.9
	5^3S	22825.7		5^3S	22824.6
Mean	5^3S	22825.2			

The effective quantum number for this value is 4.3842 which checks well with that of 4^3S .

Since, as stated previously, the effective quantum number for the 2^3P_2 term as given by Millikan and Bowen is 1.6289 and for the 3^3P_2 term as worked out above is 2.6927 it is to be expected that the 4^3P term will have a quantum number slightly above 3.7 which would indicate the 4^3P term value to be approximately 32000. This would make 3^3S-4^3P and 3^3D-4^3P approximately as follows:

	3^3S	72930.8		3^3D	52054.2
	4^3P	32000		4^3P	32000
	3^3S-4^3P	40930		3^3D-4^3P	20050

Taking the line $\lambda 2432.29$ ($\nu=41101.0$) as 3^3S-4^3P and $\lambda 4940.87$ ($\nu=20233.7$), as 3^3D-4^3P gives the following values for 4^3P :

	3^3S	72930.8		3^3D	52054.2
	3^3S-4^3P	41101.0		3^3D-4^3P	20233.7
	4^3P	31829.8		4^3P	31820.5

The difference of nine units between these two values of 4^3P is rather large but does not seem inadmissible when it is considered that they were built up from the 2^3P_2 term by two independent paths. Each

path involved a line measured by Millikan and Bowen in the neighborhood of $\lambda 1000$ where an error of one-tenth Angstrom, which is about the degree of accuracy of their work, would mean a frequency difference of ten units. Each path also involved one line reported here. An error of one-tenth Angstrom in $\lambda 2432.29$ would cause two units difference in the frequency while $\lambda 4940.87$ lay in the region where the uncertainty was between five-tenths and one Angstrom which would affect the frequency by two to four units. Taking $\nu = 31825.0$ as the value of 4^3P gives 3.7129 for the effective quantum number which is consistent with the numbers for the other 3^3P terms.

Using 4.7 as the approximate quantum number for 5^3P indicates that it lies near $\nu = 19860$ which would make 3^3D-5^3P about $\nu = 32200$. $\lambda 3102.09$ ($\nu = 32227.0$) comes very close to this.

3^3D	52054.2
3^3D-5^3P	32227.0
5^3P	19827.2

Effective quantum number—4.7040.

No other combination with 5^3P was found in the region of this work.

The first line, 3^3P-4^3D , of the second diffuse series has already been mentioned. $\lambda 2363.88$ ($\nu = 42290.5$) was classified as the second member of this series. From this is obtained the value of 5^3D .

3^3P	60510.4
3^3P-5^3D	42290.5
5^3D	18219.9

Effective quantum number—4.9069.

Millikan and Bowen located the 5^3F term by identifying $\lambda 2918.15$ as 3^3D-5^3F .

3^3D	52054.2
3^3D-5^3F	34258.3
5^3F	17795.7

The effective quantum number for this is 4.9650 while their assumed value of 4^3F would have 3.9726 as quantum number. This would indicate that 6^3F was near $\nu = 12330$ which would make 3^3D-6^3F , (52054-12330), about $\nu = 39720$. $\lambda 2515.06$ ($\nu = 39748.5$) comes very close to this. Hence

3^3D	52054.2
3^3D-6^3F	39748.5
6^3F	12305.7

Effective quantum number—5.9706.

This completes all the lines of the triplet system of B II to be expected in the range covered by this work except combinations between higher terms.

In the singlet system of B II the 3^1D-4^1F line would be one of the most probable transitions in addition to those in Table 2. The 4^1F term would not be very far removed from the 4^3F so if 4^1F is tentatively assumed as being $\nu=27800$ the 3^1D-4^1F line comes out $48400-27800=20600$. The line $\lambda 4849.6$ ($\nu=20614.3$) is the only one found near this value and accordingly was given this classification. The intensity given is weak but the line occurs in a less sensitive region of the plate where no strong lines were observed. This identification gives

3^1D	48410.3
3^1D-4^1F	20614.3
4^1F	27796.0

Effective quantum number—3.9743.

This quantum number indicates that the 5^1F term is approximately $\nu=17760$, hence 3^1D-5^1F would have a frequency of about 30650. $\lambda 3260.74$ ($\nu=30659.1$) fits this almost exactly. The recorded intensity is greater than 3^1D-4^1F but that is to be expected since it is in a much more favorable region on the plate. From this

3^1D	48410.3
3^1D-5^1F	30659.1
5^1F	17751.2

Effective quantum number—4.9713.

The higher members of this series were not observed.

The only 4^1F-8^1D lines in this region would be the higher members of the series, 8^1D or more. $\lambda 4761.4$ ($\nu=20996.5$) is about the value to be expected for 4^1F-8^1D .

4^1F	27796.0
4^1F-8^1D	20996.5
8^1D	6799.5

Effective quantum number—8.0328.

This quantum number agrees well with that for 3^1D but the classification must be considered extremely doubtful without other evidence.

The 1^1P and 1^1S term values were built up from Millikan and Bowen's value of 3^1S ($\nu = 66665.1$) and 2^1P ($\nu = 120929.4$). The effective quantum number of the latter is 1.9047 from which 3^1P and 4^1P would have frequencies of approximately 51800 and 28700 respectively. In fact they would be expected to be less than these values in accordance with the ordinary behavior of P terms. 3^1S-3^1P would be of too low a frequency to be observed here but 3^1S-4^1P , approximately 38000, should be fairly strong. Accordingly $\lambda 2566.26$ ($\nu = 38955.5$), which is the most prominent line near the predicted frequency, was taken as the line sought. This determined 4^1P as follows:

3^1S	66665.1
3^1S-4^1P	38955.5
4^1P	27709.6

Effective quantum number—3.9790.

The 3^1P term was fixed by classifying $\lambda 4290.90$ ($\nu = 23298.6$) as the combination 3^1P-4^1P .

4^1P	27709.6
3^1P-4^1P	23298.6
3^1P	51008.2

Effective quantum number—2.9328.

Further evidence in support of this assignment lies in the coherence of the 1^1S and 1^1D terms calculated below which are based on this value of 3^1P .

The effective quantum numbers of the 2^1S and 3^1S terms are 1.5026 and 2.5654 respectively, from which would be predicted the approximate term values, 4^1S , $\nu = 34400$, 5^1S , $\nu = 21000$, and 6^1S , $\nu = 14100$. The 3^1P-4^1S line would be of too low frequency to be obtained here but $\lambda 3323.34$ ($\nu = 30081.6$) corresponds to the expected frequency of the 3^1P-5^1S line. This then locates the 5^1S term.

3^1P	51008.2
3^1P-5^1S	30081.6
5^1S	20926.6

Effective quantum number—4.5762.

The higher members of this series were not observed with any degree of certainty.

$\lambda 4214.17$ ($\nu = 23722.8$) was classified as 3^1P-4^1D which gives 4^1D .

3^1P	51008.2
3^1P-4^1D	23722.8
4^1D	27285.4

Effective quantum number—4.0097.

This leads to approximate values of 17480 for 5^1D and 33528 for the term value of 3^1P-5^1D . This falls in a region where there are several iron lines in a very small range which makes positive identification very difficult. However, in measuring it was noted that one line, $\lambda 2981.53$, of the group seemed to be very slightly displaced from the line of the comparison spectrum and its identification as an iron line questionable. The wave number of this line is 33530.0 and if it is classified as the one looked for 5^1D has the wave number 17478.2 with an effective quantum number of 5.0103.

The approximate value of 6^1D would be $\nu = 12150$, which would make 3^1P-6^1D about $\nu = 38850$. $\lambda 2566.40$ ($\nu = 38953.4$) checks fairly well with this. This gives for 6^1D

3^1P	51008.2
3^1P-6^1D	38953.4
6^1D	12054.8

Effective quantum number—6.0323.

Any higher members of this series would be outside the range of this work.

The 1P and 1D terms found would indicate that the combination 3^1D-4^1P would have a value $48410.3-27709.6=20700.7$. $\lambda 4829.0$ ($\nu = 20702.7$) agrees with this.

This completes the classification of the lines found in this work which belong to B II. There should be strong $^3P'$, $^3D'$, and $^3F'$ terms in B II such as were found in Ca I, Mg I and Sr I by Russell and Saunders.¹⁰ The first $^3P^3P'$ multiplet has been located by Millikan and Bowen¹¹ at $\lambda 1624$. The $^3D^3D'$ and $^3D^3F'$ groups, however, should be of long wave length and might fall in the region here investigated. How-

¹⁰ H. N. Russel and F. A. Saunders, *Astrophys. J.*, **61**, p. 38; 1925.

¹¹ I. S. Bowen and R. A. Millikan, *Phys. Rev.*, **26**, p. 150; 1925.

ever, to identify these would require sufficient resolution to observe their fine structure.

TABLE 3. *Series lines of B II.*

Classification	λ (I. A., air)	Int.	ν (vac).
3^3S-4^3P	2432.29	5	41101.0
$2^3P_2-3^3S$	1082.10* (vac)	3	92412.8*
$2^3P_{0,1}-3^3S$	1081.88* (")	3	92432.1*
$3^3P_2-4^3S$	4472.70	2	22351.6
	4472.83*	1	22351.0*
$3^3P_{0,1}-4^3S$	4471.97	2	22355.3
	4472.12*	1	22354.5*
$3^3P_2-5^3S$	2652.81	1	37684.7
$3^3P_{0,1}-5^3S$	2652.58	1	37687.9
$3^3P_2-4^3D$	3136.85	1	31870.0
$3^3P_{0,1}-4^3D$	3135.64	1	31872.1
3^3P-5^3D	2363.88	3	42290.5
3^3D-4^3P	4940.87	1	20233.7
3^3D-5^3P	3102.09	2	32227.0
3^3D-4^3F	4121.68	10	24254.8
	4121.61*	6	24254.2*
3^3D-5^3F	2918.15	1	34258.3
	2918.13*	2	34258.5*
3^3D-6^3F	2515.06	2	39748.5
2^1S-2^1P	1362.46* (vac)	8	73396.5*
3^1S-4^1P	2566.26	3	38955.5
2^1P-3^1S	1842.83* (vac)	5	54264.3*
2^1P-3^1D	1378.95* (")	3	72519.1*
3^1P-5^1S	3323.34	3	30081.6
3^1P-4^1P	4290.90	0	23298.6
3^1P-4^1D	4214.17	0	23722.8
3^1P-5^1D	2981.53	1	33530.0 ?
3^1P-6^1D	2566.40	1	38953.4
3^1D-4^1P	4829.0	0	20702.2
3^1D-4^1F	4849.6	0	20614.3
3^1D-5^1F	3260.74	3	30659.1
$2^1S-2^3P_1$	3451.22	25	28966.0

* Observed by Millikan and Bowen.

TABLE 3. (Continued). Series Terms of B II.

Term Values		Effective Quantum Number
3^3S	72930.8*	2.4513
4^3S	38157.6	3.3989
	36655.5*	
5^3S	22825.2	4.3842
2^3P_2	165343.9*	1.6289
$2^3P_{0,1}$	165362.7*	
3^3P_2	60510.4	2.6927
	59006.5*	
$3^3P_{0,1}$	60512.5	
	59010.0*	
4^3P	31825.0	3.7129
5^3P	19827.2	4.7040
3^3D	52054.2*	2.9031
4^3D	28640.4*	3.9139
5^3D	18219.9	4.9069
4^3F	27800.0*	3.9726
5^3F	17795.7*	4.9650
6^3F	12305.7	5.9706
2^1S	194325.9*	1.5026
3^1S	66665.1*	2.5654
5^1S	20926.6	4.5762
2^1P	120929.4*	1.9047
3^1P	51008.2	2.9328
4^1P	27709.6	3.9790
3^1D	48410.3	3.0104
4^1D	27285.4	4.0097
5^1D	17478.2 ?	5.0103 ?
6^1D	12054.8	6.0323
4^1F	27796.0	3.9743
5^1F	17751.2	4.9713

* Determined by Millikan and Bowen.

BORON III

Treating B III as a hydrogenic atom Millikan and Bowen¹² identified eight lines of its spectrum and deduced the corresponding term values as given below.

¹² Millikan and Bowen, loc. cit.

TABLE 4. *B III lines and terms by Millikan and Bowen.*

Wave-lengths (I. A., vac.)	Wave-numbers	Classification
4499.0	22227	4^2F-5^2G
2077.79	48128	3^2D-4^2F
2066.41	48393	$2^2S-2^2P_2$
2067.88	48359	$2^2S-2^2P_1$
758.68	131808	$2^2P_2-3^2S$
758.47	131844	$2^2P_1-3^2S$
677.16	147676	$2^2P_2-3^2D$
677.01	147708	$2^2P_1-3^2D$
Term Values		Effective Quantum Numbers
2^2S	305938	1.7963
3^2S	125736	2.8019
2^2P_2	257545	1.9578
2^2P_1	257579	
3^2D	109870	2.9975
4^2F	61742	3.9966
5^2G	39515	4.9980

Rydberg's tables indicate the following approximate term values:

4^2S	68400	3^2P	112700	4^2D	61700
5^2S	42800	4^2P	62800	5^2D	39500
		5^2P	40100		

These approximations show that unfortunately the lines 3^2S-3^2P , ($125736-112700=13000$), and 3^2P-3^2D , ($112700-109870=2830$), have frequencies lower than could be observed in the present work. On the other hand 3^2S-4^2P , ($125736-62800=63000$), and 3^2P-4^2D , ($112700-61700=51000$), have frequencies which are too high to find here. Therefore no definite relationships can be established between the higher terms of the series and the lower terms which were obtained by Millikan and Bowen and any identification of isolated higher members of the series must be very questionable. However, it seemed desirable to attempt a tentative classification.

Eder and Valenta¹³ reported a pair at $\lambda\lambda 2267.0, 2266.4$, ($\nu=44097, \nu=44109$) for which $\Delta\nu=12$. Although this pair has not been reported by any other observers it would seem to belong to the $3^2P_1^2P_2$ term inasmuch as the frequency separation, 12, is in about the same ratio to the $3^2P_1^2P_2$ separation, 31.4, of C IV as the $2^2P_1^2P_2$ separation of B III is to the corresponding separation of C IV, viz., 34.4 to 107.4.

¹³ Eder and Valenta, loc. cit.

The identification of this pair as 3^2P-4^2S also gives consistent values of the terms 3^2P and 4^2S . Millikan and Bowen's 2^2S and 3^2S had quantum numbers of 1.7963 and 2.8019 respectively so 3.8050 was assumed for 4^2S by analogy with Li I, the 2^2S , 3^2S , and 4^2S terms of which have quantum number 1.588, 2.595 and 3.598 respectively. This makes $4^2S=68184$ and

4^2S	68184	4^2S	68184
$3^2P_2-4^2S$	44097	$3^2P_1-4^2S$	44109
3^2P_2	112281	3^2P_1	112293

Effective quantum number for $3^2P-2.9650$.

Of the lines arising from higher series terms, the approximate term values on page 19 indicate that 4^2S-5^2P , 4^2P-5^2S should be in the region studied. No lines have been found corresponding to these pairs.

For 4^2P-5^2D however:

4^2P	62800
5^2D	39519
4^2P-5^2D	23281

$\lambda 4311.9$ ($\nu=23185.2$) comes very close to this and if it is taken as the line sought it makes $4^2P=62704$, effective quantum number 3.9677, in close agreement with 2^2P and 3^2P .

Also

4^2D	61758
5^2P	40100
4^2D-5^2P	21658

$\lambda 4677.9$ ($\nu=21371.2$) apparently corresponds to this and makes $5^2P=40387$, quantum number 4.9436.

TABLE 5. *Series lines of B III.*

Classification	λ (I. A., air)	ν (vac.)
$2^2S-2^2P_2$	2065.75*	48393*
$2^2S-2^2P_1$	2067.22*	48359*
$2^2P_2-3^2S$	758.68* (vac.)	131808*
$2^2P_1-3^2S$	758.47* (")	131844*
$3^2P_2-4^2S$	2267.0**	44097
$3^2P_1-4^2S$	2266.4**	44109
$2^2P_2-3^2D$	677.16* (vac.)	147676*
$2^2P_1-3^2D$	677.01* (")	147708*
4^2P-5^2D	4311.9	23185
4^2D-5^2P	4677.9	21371
3^2D-4^2F	2077.11*	48128*
4^2F-5^2G	4497.7 *	22227*

* Observed by Millikan.

**Observed by Eder and Valenta.

Series terms of B III.

Term Values		Effective Quantum Number
2^2S	305938*	1.7963
3^2S	125736*	2.8019
4^2S	68184	3.8050
2^2P_2	257545*	1.9578
2^2P_1	257579*	
3^2P_2	112281	2.9650
3^2P_1	112293	
4^2P	62704	3.9677
5^2P	40387	4.9436
3^2D	109870*	2.9975
4^2D	61758	3.9975
5^2D	39519	4.9975
4^2F	61742*	3.9966
5^2G	39515*	4.9980

* Determined by Millikan.

IV. SUMMARY OF RESULTS

A glass spark-box more convenient to handle and adjust and subject to fewer insulation difficulties has been developed to replace the metal box previously used.

About one hundred new boron lines have been found in the region investigated and about twenty of these lines have been classified in series.

The experimental part of this work was carried out in the Physical Laboratory of the University of Michigan.

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